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THE MANGANESE MINERALS OF THE SUNNYSIDE VEINS, EUREKA GULCH, COLORADO

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INTRODUCTION

Since 1926 the cooperative geologic survey carried on jointly by the State of Colorado and the United States Geological Survey has undertaken the remapping of a number of the San Juan mining districts. Much attention has been given to the mineralogy of the veins since only a few of the San Juan ores have been studied in the light of modern methods and advances in the science of mineralogy. The ores of this region are chiefly of late Tertiary age and occur principally in fissure veins in the Tertiary volcanic rocks. Among the most interesting of the veins are those that contain a large proportion of hypogene manganese minerals. The writer's interest in the apparently erratic distribution of the highly manganiferous gangues and the paragenetic relations of the different manganese minerals has been encouraged by Mr. D. F. Hewett of the Geological Survey. Certain characteristic paragenetic relations between the manganese minerals of the Bonanza district[2] in the northeastern San Juan and of the manganiferous base-metal ores of the Camp Bird and nearby areas in the western San Juan indicated similar conditions of formation in widely separated areas of this volcanic province. Hewett and Rove[3] have called attention to certain seemingly constant relations between alabandite and rhodonite and rhodochrosite in many districts of the United States and other parts of the world. It seems possible that the manganese minerals may provide a useful guide in classifying and defining conditions of vein formation and that a preliminary study of the manganese minerals of the Sunnyside mine at Eureka may give further information on this problem, since the veins are noted for the large bodies of rhodonite associated with base-metal ores.

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[1] Published by permission of the Director of the United States Geological Survey and that of the Chairman of the State Geological Survey Board of Colorado.

[2] Burbank, W. S., and Henderson, C. W., Geology and ore deposits of the Bonanza mining district, Colorado: *U. S. Geol. Survey, Prof. Paper* **169**, pp. 70, 86, 126, 127, and Pl. 13-B, 1932.

[3] Hewett, D. F., and Rove, O. N., Occurrence and relations of alabandite: *Econ. Geol.*, **25**, pp. 36–56, 1930.

In 1931 Mr. E. N. Goddard and the writer visited Eureka, but as the mine was not operating at the time of the visit it became impracticable to make underground studies in the short time available. However, numerous specimens of the manganese minerals were collected from the waste pile near the mill at Eureka. These were selected at random from a very large pile although some care was taken in selecting representative specimens of as many different types and textures of manganiferous gangue as was practicable. A study of these specimens with the advantage of advice and assistance from Messrs. Hewett, C. S. Ross and W. T. Shaller of the Geological Survey revealed at least five or six manganese minerals unreported from this particular deposit and several of which have been reported from only one or two localities in the United States. Since the original plan of studying the vein cannot be carried to completion in the immediate future, it has been decided to report these occurrences.

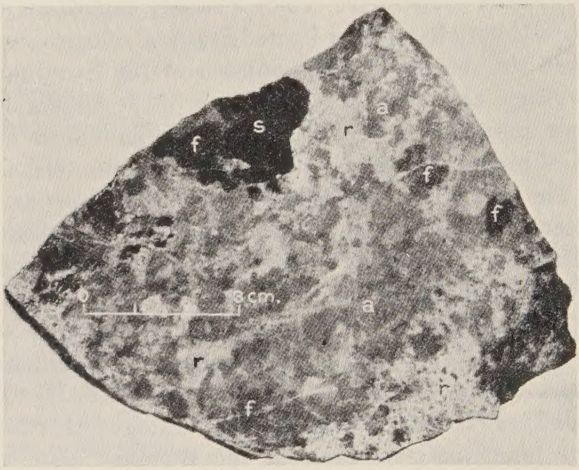

FIG. 1. Alleghanyite (a), tephroite (locally with alleghanyite), and friedelite (f), partly replaced by rhodonite (r). S, fragment of sphalerite of an earlier stage. Specimen illustrates influence of minute fractures on replacement phenomena.

GEOLOGY AND LOCATION OF THE SUNNYSIDE VEIN SYSTEM

The principal workings of the Sunnyside mine are located about 7 miles north-northeast of Silverton and about 3 miles northwest of Eureka in the Silverton quadrangle, at elevations ranging between 11,000 feet (3,353 meters) and a little over 13,000 feet (3,960 meters). The mine has been one of the largest producers of base-metal ore in the San Juan region, and the mill at Eureka, which was the first plant in North America to practice selective flotation on the complex ores of the Rocky Mountain region, yielded both zinc and lead concentrates carrying valuable amounts of silver and gold.[4] The outcrop of the vein was located in 1873 and the first work on it exposed rich gold ore, but this was soon exhausted. The large scale mining and milling operations of the United States Smelting, Refining & Mining Company were started in 1912 after a series of intermittent operations and attempts to treat the lower grade and complex ores.

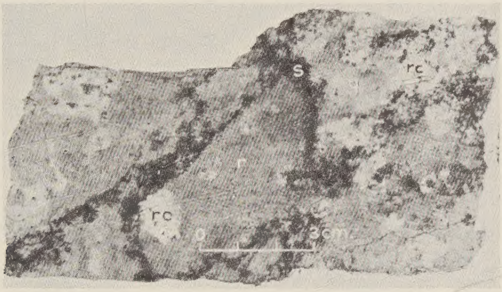

FIG. 2. Massive rhodonite (r), brecciated and partly replaced by late sulphides (s), rhodochrosite (rc), and quartz (q).

The country rock of the area about the Sunnyside consists of lava flows, chiefly latitic, which form the middle part of the Silverton volcanic series of Miocene age.[5] The volcanic rocks, including the Potosi volcanic series which is now eroded in this particular area, originally attained a thickness probably of 6,000 to 8,000 feet (1829 to 2438 meters). At some time following the eruption of the Potosi series large bodies of magma invaded the crust and caused regional fracturing and faulting, which resulted in the sinking of a large block of crust in the central part of the Silverton quadrangle below the level of the surrounding areas.[6] The great faults that form part of the Sunnyside vein system belong to the fault systems that define the margins of this downfaulted block. This structure is important in considering the nature of the mineralization at the Sunnyside mine, since these major faults and their immediately attendant systems of fracturing largely furnished the most direct channels through which the mineralizing solutions ascended. The mineralogic evidence conforms with the structural evidence in that the veins occupy channels which carried great volumes of hot solutions, and that the ores and gangues represent certain relatively high temperature facies of the San Juan mineralization. This mineralization probably occurred in late Miocene or earliest Pliocene time, and under a cover of approximately 4,000 to 5,000 feet (1,219 to 1,524 meters).

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[4] Robie, E. H., Lead-zinc flotation at Sunnyside: *Eng. and Min. Jour.-Press,* **121,** pp. 757–762, 1926.

[5] Cross, W., and Larsen, E. S., San Juan region of southwestern Colorado: *U. S. Geol. Survey Bull.* (In preparation.)

The Sunnyside vein system consists of a number of different veins, which range from 20 to 80 feet (6 to 24 meters) in width, and have been stoped to a width of over 50 feet (15 meters). The principal zone of faulting and fissuring strikes northeast and along it there has been a displacement of approximately 1,000 feet (305 meters), but northwest and east-west fault fissures are also mineralized. Hulin[7] presents evidence to show that the vein growth proceeded by successive reopening of the Sunnyside fissures caused by faulting movements along them. He stated[8] that ". . . two of the most important ore shoots which have been developed are controlled by variation in strike of the vein fissure. . . . Minor premineral cross-faults modify these ore shoots to some extent."

Hulin[9] furthermore recognized three principal mineralogic stages in the formation of the Sunnyside veins, an early stage of barren pyritic quartz veins, a second stage of base metal ores, and a third stage of rhodonite veins and ribs. He considered these stages as part of a continuous period of mineralization, and in pointing out the importance of the time of reopening of the fissures in relation to the stages of mineralization stated,[10] "Here again it is manifest that ore shoots must be restricted to those portions of the veins receiving the mineralization of the second stage. Portions of veins receiving mineralization only during the first stage will consist of barren quartz, whereas those portions of the veins formed during the third stage consist essentially of barren rhodonite." Thus it seems clear from Hulin's descriptions of the veins that both the base metal ores and the bodies of manganese silicates were formed by the filling of open fissures and not to any great extent by replacement of wall rock.

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[6] Burbank, W. S., Vein systems of the Arrastra Basin, and regional geologic structure in the Silverton and Telluride quadrangles, Colorado: *Colo. Sci. Soc. Proc.* (In preparation.)

[7] Hulin, C. D., Structural control of ore deposition: *Econ. Geol.*, **24,** pp. 22–30 32, and 39–42, 1929.

[8] *Op. cit.*, pp. 38, 39, and Fig. 8, B.

[9] *Op. cit.*, p. 32, and Fig. 5.

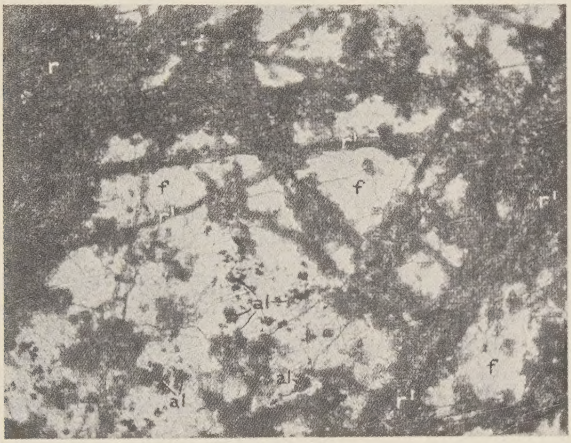

FIG. 3. Friedelite (f), partly replaced by early rhodonite (r), and all cut by later veinlets of rhodonite (r'). al, alabandite. Photomicrograph of thin section in ordinary light. (37 diameters.)

The principal minerals of the veins consist of quartz and pyrite of the early stage, of sphalerite, galena, and chalcopyrite that followed in overlapping deposition, and of a little tetrahedrite. According to Weinig and Palmer,[11] a part of the sphalerite of the Sunnyside ore is the marmatite variety. The third stage, with which most or all of the manganese minerals described in this paper are presumably associated, consisted chiefly of rhodonite with the other manganese minerals and minor amounts of still later sulphides. Free gold in quartz is found with the ore bodies and has been observed cutting both the base metal ores and the later rhodonite. Calcite, fluorite, rhodochrosite, and huebnerite have also been recognized in the veins.

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[10] *Op. cit.*, p. 32.

[11] Weinig, A. J., and Palmer, I. A., The trend of flotation: *Colo. School of Mines Quart.*, **24,** No. 4, p. 52, 1929.

The manganiferous gangues with which the remainder of this paper will deal contain in addition to rhodonite different quantities of the following minerals: alabandite, alleghanyite, friedelite, helvite, rhodochrosite, and tephroite, with small quantities of other perhaps supergene minerals such as neotocite. The hypogene manganese minerals will be described briefly and following these descriptions a review of the paragenetic relations as observed in the specimens will be given. For the mineralogic work ten representative specimens were sawed, five of which were polished; numerous thin sections were also prepared.

The Manganese Minerals

Alabandite (MnS). The sulphide of manganese, alabandite, forms minute grains and veinlets mostly of microscopic size, which are irregularly distributed through the manganese silicates friedelite, alleghanyite, and rhodonite (Fig. 3). The largest grains of alabandite seen were about 0.75 millimeter in diameter. No large masses or crystals of this mineral were found. The alabandite is recognizable by its bright green color as seen by strong transmitted light in thin section, and by the odor of hydrogen sulphide given off when small quantities of it are treated with hot acid or heated in the closed tube with friedelite. The alabandite is associated with a little pyrite, sphalerite, galena, and probably chalcopyrite.

Alleghanyite ($5MnO \cdot 2SiO_2$). The silicate of manganese, alleghanyite,[12] occurs in five of the specimens studied, usually in association with tephroite. It is more abundant than tephroite but less abundant than rhodonite in these particular specimens. The largest grains seen in thin sections range from 0.8 to 1.6 millimeters in length and 0.1 to 0.3 millimeter in width. The color of the mineral on polished faces of the specimens is of a darker grayish-pink as contrasted with the lighter pink of the rhodonite and the greenish-gray color of the tephroite. The fine twinning lamellae which are a characteristic feature of this mineral lie at right angles to the elongation of the grains of the above dimensions, but grains oriented so as to show no twinning lamellae are generally more nearly equidimensional in cross section. The lamellae are generally narrow and, like those in the Bald Knob mineral, show symmetrical extinction in sections perpendicular to the axial plane. A few individuals show combined double twins that present a herringbone pattern with symmetrical and essentially equal extinction in each twin when the section is at right angles to the long twinning plane. A photomicrograph showing the general shape and size of the alleghanyite grains is shown in Figure 4.

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[12] Ross, C. S., and Kerr, P. F., The manganese minerals of a vein near Bald Knob, North Carolina: *Am. Mineralogist*, **17**, pp. 7–13, 1932.

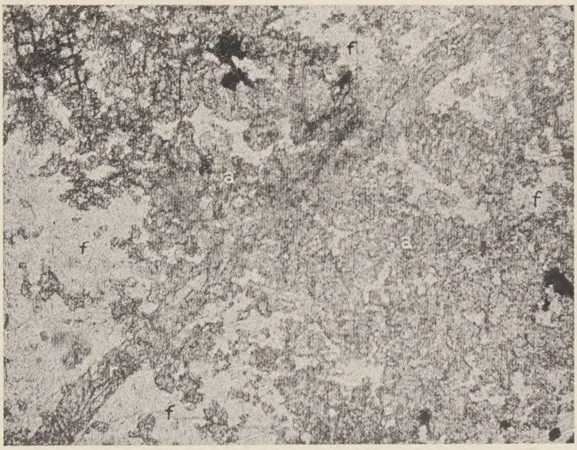

FIG. 4. Alleghanyite (a), and friedelite (f), cut by veinlet of rhodonite (r). Photomicrograph of thin section in ordinary light. (68 diameters.)

The determined optical properties of this alleghanyite are given in the following table together with those of alleghanyite from the type locality.

No chemical tests, other than the determination of manganese, have been made to confirm the identification of the mineral, but the optical and general physical properties appear sufficiently conclusive.

Alleghanyite was first discovered by C. S. Ross in association with spessartite, rhodonite, tephroite, galaxite (a new manganese spinel), manganiferous calcite, and other minerals near Bald Knob, North Carolina, and described by Ross and Kerr in the paper re-

TABLE 1. OPTICAL PROPERTIES OF ALLEGHANYITE

	Sunnyside mine, Colo.	Bald Knob, N. C.[1]
Indices of refraction	$\alpha=1.756$ $\beta=1.776$ $\gamma=1.790$	$\alpha=1.756$ $\beta=1.780$ $\gamma=1.792$
Birefringence	.034	.036
2 V	75°–80°	72°
Dispersion of the axes	$r>v$	$r>v$
Optical character	Negative	Negative

[1] Ross and Kerr, *Op. cit.*, pp. 7–10

ferred to above. This occurrence at the Sunnyside Mine is the second verified occurrence although Ross and Kerr[13] call attention to a mineral described by Rogers from an erratic bowlder near San Jose, California, which has similar physical properties.

FRIEDELITE. A chlorine-bearing hydrous silicate of manganese, for which the general formula given in Dana's Mineralogy[14] is $6MnO \cdot 2Mn(OH, Cl)_2 \cdot 6SiO_2 \cdot 3H_2O$, occurs in association with alleghanyite, tephroite, and rhodonite. The mineral forms fine-grained, translucent masses of a rose-red or brownish-red color. In thin sections, the masses are seen to be made up of fine cleavable scales which mostly range from 0.01 to 0.02 millimeter in diameter grown compactly together. Coarser scales are also present and are evidently due to the stage of formation and amount of recrystallization the mineral has undergone. Where the mineral crystallized late it forms distinctly tabular crystals 0.06 to 0.13 millimeter in diameter, which are similar to the common rhombohedral form of friedelite.

When the mineral is heated in a closed tube it yields a considerable volume of water which reacts for chlorine. An odor of hydrogen sulphide, sometimes detectable on heating, is probably due to small grains of alabandite which can be seen in the friedelite under the microscope. Some arsenic, as well as chlorine, was found to be present in the mineral by qualitative wet tests kindly made by Dr. Schaller. In the absence of definite quantitative determinations of these constituents the distinction between friedelite and schallerite,[15] the analogous arsenic-bearing manganese silicate, rests upon comparison of optical properties. The optical properties of the Sunnyside mineral correspond more closely to those of friedelite than to the type specimens of schallerite from Franklin, N. J., as shown in the following table:

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[13] *Op. cit.*, p. 13.

[14] Ford, W. E., Dana's Textbook of Mineralogy, 4th edition, p. 590, John Wiley and Sons, Inc., N. Y., **1932.**

TABLE 2. OPTICAL PROPERTIES OF FRIEDELITE AND SCHALLERITE

	Freidelite Sunnyside mine, Colo.	Freidelite Franklin, N. J.[1]	Friedelite Sweden[2]	Schallerite Franklin, N. J.[3]
Indices of refraction.......	$\omega=1.657$	1.656	1.664	1.704
	$\epsilon=1.625$	1.62	1.629	1.679
Birefringence.............	0.032	0.03	0.035	0.025
Optical character..........	Negative	Negative	Negative	Negative
2 V.....................	0°, or a few degrees	0°	Small	0°

[1] Bauer, L. H., and Berman, H., Friedelite, schallerite, and related minerals: *Am. Mineralogist*, **13**, pp. 342, 343, Table 1, No. 4, and Table IIa, No. 2, 1928.

[2] Larsen, E. S., Microscopic determination of the non-opaque minerals: *U. S. Geological Survey, Bull.* **825**, p. 77, 1921.

[3] Bauer and Berman, *Op. cit.*, p. 343.

The friedelite from Franklin, N. J., the optical properties of which are given in the table above, contained 2.32 percent of chlorine, and 1.15 percent of As_2O_3, but the members of this group of minerals are probably not sufficiently well known for the optical and chemical properties to be correlated closely. The Sunnyside Mine seems to be the only locality in the United States other than Franklin, N. J., from which this mineral has been recorded.

HELVITE, $3(Mn, Fe)BeSiO_4\ MnS$. The comparatively rare species, helvite, was found in three specimens of the mixed silicates of manganese. It forms small grains not over a few millimeters in diameter that are usually near small grains of pyrite or other common sulphides. The brilliant honey-yellow color, however, makes it conspicuous. The mineral was identified by its isotropic character, refractive index near 1.74, presence of beryllium, and absence of zinc, as determined by spectrographic tests kindly made by Mr. George Steiger of the U. S. Geological Survey.

Under the microscope some grains of the mineral are seen to be partly altered to a yellowish birefracting product, and the clear grains show small tetrahedral-shaped cavities containing minute spherical bodies. The small particles of sulphide nearest to the mineral appeared in several instances to be pyrite, rather than either alabandite or sphalerite.

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[15] Gage, R. B., Larsen, E. S., and Vassar, H. E., Schallerite, a new arseno-silicate mineral from Franklin Furnace, New Jersey: *Am. Mineralogist*, **10**, pp. 9–11, 1925.

This is the second record of the occurrence of helvite in the United States. The only locality is the area near Amelia Court House, Va., where the mineral occurs in cracks in orthoclase and spessartite at the mica mines,[16] in association with monazite, microlite, allanite, and other pegmatitic minerals. The most common foreign occurrences of helvite also appear to be pegmatitic or contact zone associations, but Dana records it from Kapnik, Hungary, on quartz and rhodochrosite.

Rhodochrosite ($MnO \cdot CO_2$). The carbonate of manganese is found in small amounts at least in practically all of the specimens, and in some of them it is abundant. It is usually less common than rhodonite. The carbonate has replaced many of the silicates and locally some of the sulphides, so that it occurs in veinlets and irregular replacement masses. The indices of refraction indicate that all of the carbonate tested is high in manganese and is rhodochrosite rather than manganocalcite. In one specimen the lowest value of the index, ω, was about 1.79, but other specimens showed still higher values so that according to the data given by Krieger[17] the carbonate contains 80 to 85 percent or more of $MnCO_3$.

Rhodonite ($MnO \cdot SiO_2$). The material from the dump at Eureka and the specimens studied, contain much more rhodonite than the other manganese silicates. The grains of rhodonite range from about 0.1 to 1.0 millimeter in diameter and well formed crystals, about one millimeter in maximum diameter, were found in small vugs in the massive rhodonite gangue. The color of the rhodonite masses appears to vary chiefly according to their texture. Some specimens are very pale pink but others are deep pink. Little variation could be detected in the indices of refraction.

Some rhodonite crystals show twinning but in general the mineral is distinguished by the sparseness of twinning whereas grains of alleghanyite uniformly show it. The optical properties of the rhodonite in several massive specimens were determined, and of some small transparent rose-pink crystals in a cavity as well.

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[16] Lewis, H. C., An American locality for helvite: *Proc. Acad. Nat. Sci. Phila.*, **34,** pp. 100–102, 1882.

Dana, E. S., System of mineralogy, 6th Ed., p. 435, **1909.** John Wiley and Sons, N. Y.

[17] Krieger, P., Notes on an x-ray diffraction study of the series calcite-rhodochrosite: *Am. Mineralogist,* **15,** pp. 23–29, 1930.

TABLE 3. OPTICAL PROPERTIES OF RHODONITE

	Sunnyside mine, Colo.	Vittinge, Finland[1]
Indices of refraction	$\alpha=1.733$ $\beta=1.736$ $\gamma=1.747$	$\alpha=1.733$ $\beta=1.737$ $\gamma=1.747$
Birefringence	0.014	0.014
Dispersion	$r<v$	—
2 V	55°–60°	61°
Optical character	Positive	Positive

[1] Sundius, N., On the triclinic manganiferous pyroxenes: *Am. Mineralogist*, 16, pp. 488–489, and pp. 517, 518, 1931.

The chemical analysis of the rhodonite from Vittinge shows 94.69 percent of $MnSiO_3$, and only 3.05 percent $CaSiO_3$, and the close correspondence of its optical properties with those of the Sunnyside rhodonite suggests that this rhodonite also has a high manganese content.

TEPHROITE ($2MnO\cdot SiO_2$). The manganese olivine, tephroite, was identified in four of the specimens as small anhedral grains nearly always associated with larger masses of alleghanyite. The grain size ranges from 0.1 to 0.35 millimeter in diameter. The color of the mineral is gray and a mottled appearance is noticeable in polished specimens containing much of the mineral. On the surfaces of pieces that have been exposed on the dump tephroite assumes a darker color than the other minerals and it probably weathers more quickly. The relative susceptibility to weathering of the other silcates is not clearly shown.

At first the tephroite in thin section was not distinguished from anhedral grains of alleghanyite that were so oriented as not to show the twinning lamellae. The presence of tephroite was first determined by a study of the powdered material by the immersion method, and it could then be rather readily identified in thin sections. Tephroite commonly shows a brownish amorphous alteration product around the edges and in cracks; it also has a smaller optic axial angle than alleghanyite.

Table 4 presents the optical properties of tephroite from the

Sunnyside mine and for comparison those of tephroite from Franklin, N. J., and Bald Knob, N. C.

TABLE 4. OPTICAL PROPERTIES OF TEPHROITE

	Sunnyside mine, Colo.	Franklin, N. J.[1]	Bald Knob, N. C.[2]
Indices of refraction	$\alpha=1.771$ $\beta=1.800$ $\gamma=1.815$	$\alpha=1.770$ $\beta=1.792$ $\gamma=1.804$	$\alpha=1.785$ $\beta=1.803$ $\gamma=1.820$
Birefringence	0.044	0.034	0.035
Dispersion	$r>v$	$r>v$	$r>v$
2 V	70° ±	large	72°
Optical character	Negative	Negative	Negative

[1] Larsen, E. S., The microscopic determination of the nonopaque minerals: *U. S. Geol. Survey, Bull.* **679**, p. 143, 1921.

[2] Ross and Kerr, *Op. cit.*, p. 5.

Tephroite is not an uncommon mineral of the deep vein zones of manganese deposits that lie largely in the crystalline rocks of the Appalachian belt. This occurrence seems to be the first in the United States in the younger deposits that have thus far been considered to be epithermal.

PARAGENETIC RELATIONS

Since the interrelations of the different minerals in veins were not studied in place, it would not be wise to correlate confidently the relations observed in the specimens with the general paragenetic relations in the mine recorded by Hulin and mentioned in the introduction. This might result in misleading if not wholly erroneous conclusions. However, the relations observed between the different silicate minerals are probably worth recording briefly as these seem to be fairly constant in all of those specimens studied.

Several specimens showed distinct veins of the manganese silicates cutting through earlier masses of sulphides and quartz, or showed fragments of sulphides included within the silicates so that it seems clear that a part of the massive sulphides was earlier than any of the minerals herein described. Practically all of the specimens, however, showed small amounts of galena, sphalerite, pyrite, and chalcopyrite, as well as alabandite, which are interlayered in the silicates of manganese or were deposited somewhat later than the silicates. Some of the more evident relations are illustrated in Figures 2 and 3. In what follows the relations between sulphide and gangue minerals concern only those sulphides contemporaneous with or later than the manganese minerals.

What at first appears to be a somewhat anomalous feature of the paragenesis is that the hydrous silicate, friedelite, wherever found in appreciable amounts in association with the other silicates, is one of the earliest of the manganese minerals. The largest masses found in the specimens ranged from 2 to 10 millimeters in diameter, but these were veined and partly replaced by tephroite, alleghanyite, rhodonite, and rhodochrosite. The alleghanyite tends to form sheaf-like or irregular clusters of crystals that appear to have grown at the expense of friedelite. These clusters are clearly related to fissures or cracks from which the crystals advanced into the unreplaced friedelite. Rhodonite crystals exhibit exactly the same type of replacement forms along the borders of later veinlets of rhodonite cutting friedelite. The peculiar manner in which the alleghanyite crystals have grown suggests that the friedelite is possibly replacing the anhydrous silicates, which have the appearance around their edges of much corroded and frayed crystals; but that this appearance is deceiving is shown by comparison with similar crystals growths about the distinct and later veinlets of rhodonite. Growths of alleghanyite in friedelite are illustrated by the photomicrograph shown in Fig. 4. Nuclear masses of tephroite grains within the larger alleghanyite masses show that this mineral was also one of the first to form at the expense of friedelite, and from its spacial relations was presumably formed before the bulk of the alleghanyite. On the other hand one specimen shows that some of the friedelite is later than tephroite and perhaps indicates local repetition of the early stages of paragenesis.

Rhodonite was later than alleghanyite, and free crystals were deposited in vugs after the bulk of the anhedral granular mass of rhodonite had formed. The formation of rhodonite appears to have been interrupted at least once by renewed fracturing, with the result that the earlier manganese silicates as well as the bulk of the rhodonite is cut by interlacing veinlets of later rhodonite. The process of replacement of most of the earlier silicates by rhodonite is shown both by the thin sections and the polished faces of the specimens. (Figures 1, 3, 4.)

Whether or not most of the rhodonite formed at the expense of earlier friedelite or of other manganese silicates cannot be determined conclusively from the study of small hand specimens. In several of the thin sections small nests of comparatively large sized friedelite crystals occur interstitially in the midst of masses of rhodonite crystals. It is not clear whether these represent remnants of recrystallized friedelite remaining from the earlier finer grained mass, or whether they represent a later generation of friedelite, transported and redeposited. It is perhaps significant however that friedelite crystals could not be found in any of the small vugs in the gangue, although rhodonite, rhodochrosite, and several different sulphides were found in them.

Rhodonite is the only manganese silicate found associated directly with or intergrown with quartz. No quartz was found in any vugs in the mixed silicate gangue, nor were quartz veinlets cutting these silicates noted. Most of the quartz in the Sunnyside ores evidently belongs to stages of vein formation preceding these manganese minerals. However, there is evidently some later quartz or quartz and free gold that was deposited with or later than rhodonite, but which does not happen to be represented in the particular specimens of friedelite, alleghanyite, and tephroite examined. As set forth below, the silica content of the solutions evidently increased following deposition of the earlier silicates until finally rhodonite and quartz crystallized together. As tephroite and alleghanyite are orthosilicates and the ratio of maganese to silica in them is less than 1 to 1, the ratio in the metasilicate rhodonite, it is possible that a hiatus in the deposition of quartz exists at their particular stage of formation in the Sunnyside veins.

The sulphide, alabandite, appears to have formed during the crystallization of the silicates, chiefly with friedelite and alleghanyite, but also with the rhodonite. Its distribution is unrelated to the later lines of fracturing along which the latest rhodonite and along which the rhodochrosite were formed. The helvite cannot be exactly placed in the sequence but may have formed late in the crystallization of rhodonite, and is definitely earlier than rhodochrosite. Helvite was seen in only one thin section where it was interstitial among crystals of rhodonite. Sphalerite, galena, chalcopyrite, and small amounts of pyrite and possibly tetrahedrite filled in along cracks and replaced brecciated rhodonite as shown in Fig. 2. The formation of some of these sulphides possibly in part overlapped that of helvite.

Rhodochrosite was the last of the manganese minerals to form and it has partly replaced all of the earlier ones and some of the common sulphides. This sequence is the same as observed by Hewett and Rove.[18]

The general picture obtained from these paragenetic relations is that the solutions which brought in the manganese were at first low in silica, high in manganese, and contained sufficient chlorine to permit the deposition of massive friedelite. Later solutions which were presumably less acid but still low in silica caused the dehydration of the friedelite and the formation of tephroite and alleghanyite. This dehydration may have been caused by an increase in temperature of the emanations. As the silica content of these solutions increased, rhodonite began to form and continued until locally rhodonite and quartz were formed together. Probably the later rhodonite was formed in part by direct precipitation in openings rather than entirely by replacement of the earlier silicates. The late rhodochrosite and any other carbonates that are present may be attributed to the attack of carbonated water as they do not necessarily indicate further introduction of manganese from the original source.

Conclusions as to the classification of the different manganese minerals in the common temperature schemes cannot be made safely with the data at present available on their occurrence and paragenesis. However, from the general mineralogy of the Sunnyside veins as compared with the more distant and characteristic epithermal facies of the San Juan veins, the Sunnyside mineralization may be tenatively assigned to facies commonly defined as mesothermal.

The not uncommon occurrence of tephroite in the deep vein zones of the Appalachian region indicates that this mineral is formed more typically at great depths under hypothermal or pyrometasomatic conditions. Its presence in small quantities in the Sunnyside veins indicates however that it may form likewise at comparatively shallow depths (5,000 feet or less) when other factors in its formation are favorable, and lends support to the possibility that many of the San Juan veins were formed at temperatures higher than those generally accepted for the veins of this region.

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[18] Hewett, D. F., and Rove, O. N., Occurrence and relations of alabandite: *Econ. Geol.*, **25**, pp. 55–56, 1930.

COLUSITE, A NEW MINERAL OF THE SPHALERITE GROUP

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INTRODUCTION

Small amounts of tin in ores shipped from the Leonard, West Colusa, Mountain View and Tramway Mines of the Anaconda Copper Mining Company at Butte, Montana, have been noted for a number of years. The tin-bearing mineral was provisionally named "colusite" by Mr. Reno H. Sales, Chief Geologist of the Anaconda Company. The mineral was first noted on the 1200 foot level of the Leonard Mine near the west end of the Piccolo claim, south of the Colusa claim. The latter was one of the earliest locations in the district, and therefore it seemed appropriate to name the new mineral "colusite."

Samples of colusite from the Leonard and Mountain View Mines gave the following partial analyses:

Mine	*Cu*	*Sn*	*Fe*	*As*	*Sb*	*Zn*	*S*	*Te*	*Bi*	*Total*
Leonard	48.0	6.9	?	6.8	2.6	0.0	27.5	3.0	0.0	94.8%
Mt. View	46.9	5.8	3.6	8.4	0.64	0.9	29.2	0.4	0.0	95.8%

In June 1930 the 2900 and 3000 levels of the Tramway Mine opened a copper ore body containing unusually high percentages of tin. At that time the writer collected a number of specimens from the Number Seven Vein on the 2900 level and later additional specimens were furnished by the Anaconda Copper Mining Company.

The only reference to colusite in the literature known to the writer is that of Schneiderhöhn[1] in which he says, "Apparently belonging to the tetrahedrite group is the tin-rich, but not yet thoroughly studied "colusite" from Butte, Montana."

ACKNOWLEDGMENTS

The writer is indebted to the Geological Department of the Anaconda Copper Mining Company for the partial analyses given, and to Mr. Murl H. Gidel and Mr. Edward P. Shea of the Ana-

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[1] Schneiderhöhn, H., and Ramdohr, P., Lehrbuch der Erzmikroskopie, 2nd Edition, *Berlin*, **1931**, p. 433.

conda Geological Staff for furnishing fresh material for study. To Mr. Reno H. Sales the writer is indebted for a critical reading of the manuscript. The writer is especially grateful to Drs. E. S. Bastin and D. J. Fisher of the University of Chicago for the use of a laboratory and microscope during the summer of 1931 when part of the study was carried on, and for helpful criticism of the paper.

Mineralogy of Colusite

Colusite is bronzy in color, rather brittle, and decidedly granular in structure. It has a hardness of 3 to 4 in the Mohs' scale. A small specimen of unusual purity had a specific gravity of 4.2. Colusite gives a black streak. It has no cleavage. According to a personal communication from Dr. D. J. Fisher at the University of Chicago, a small crystal fragment showed two faces which suggest the tris-octahedron (221) form. That colusite is isometric is shown conclusively in the following article of this journal.[2]

The following complete chemical analyses were made of material collected from the Number Seven Vein, 2900 level of the Tramway Mine at Butte:

Elements	No. 1	No. 2	Average
Tin	6.45%	6.83%	6.64%
Copper	35.82	35.82	35.82
Antimony	0.57	0.59	0.58
Arsenic	2.09	2.91	2.50
Chromium	tr.	tr.	tr.
Zinc	0.90	0.91	0.90
Manganese	none	none	none
Tellurium	3.04	2.91	2.97
Molybdenum	8.80	8.80	8.80
Tungsten	tr.	tr.	tr.
Iron	17.75	19.00	18.37
Sulphur	24.20	24.20	24.20
Total	99.62%	101.97%	100.78%

Analyses by S. T. Gross, Graduate student in chemistry at the California Institute of Technology, Pasadena, California.

The reader is referred to the article by Zachariasen cited above for a discussion of the chemical structure of colusite.

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[2] Zachariasen, W. H., *X*-ray Examination of Colusite, $(Cu, Fe, Mo, Sn)_4$ $(S, As, Te)_{3-4}$, a New Member of the Sphalerite Group, *Am. Mineral.*, Vol. **18**, pp. 534–537, 1933.

OBSERVATIONS ON THE POLISHED SURFACE

Optical Character—Isotropic.
Hardness—low.
Color—bronzy gray.
Reagents:

HNO_3—positive. Tarnishes brown. Etched to pitted surface.

HCl—same as HNO_3. Fumes tarnish.

KOH—negative.

KCN—positive. Solution colors pink. Slight tarnish which washes off.

$HgCl_2$—negative.

$FeCl_3$—negative.

Gives positive tests for tin and copper according to the methods prescribed by Short.[3] In making the tin tests cesium chloride rather than rubidium chloride was used.

PARAGENETIC RELATIONS

Other minerals associated with colusite are pyrite, tetrahedrite, bornite, chalcocite, and quartz.

Pyrite appears as yellow specks in the hand-specimen. Under the microscope it occurs as irregular grains imbedded in other minerals. It shows no unusual features.

Colusite and tetrahedrite occur intimately associated in irregular areas having sharp curving boundaries and outlines. Colusite makes up the greater volume, and generally encloses the tetrahedrite, but in some places the tetrahedrite encloses the colusite. See Figs. 1, 2, and 4. The fact that even under the high power of the microscope the boundaries are still smoothly curving and clean-cut indicating no replacement of either mineral by the other, and the fact that both minerals contain areas of the other, suggest that the two minerals are essentially contemporaneous, and that their texture is the result of unmixing. Both minerals are at least partly later than the early generation of pyrite, small grains of which they enclose.

Mottled intergrowths of chalcocite and bornite, such as figured by Schwartz,[4] occur in small veinlets traversing colusite and tetra-

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[3] Short, M. N., Microscopic Determination of the Ore Minerals: *U. S. Geol. Survey, Bull.* **825,** 1931.

[4] Schwartz, G. M., Bornite-Chalcocite Intergrowths: *Econ. Geol.*, Vol. **XXIII,** Fig. 1, p. 389, 1928.

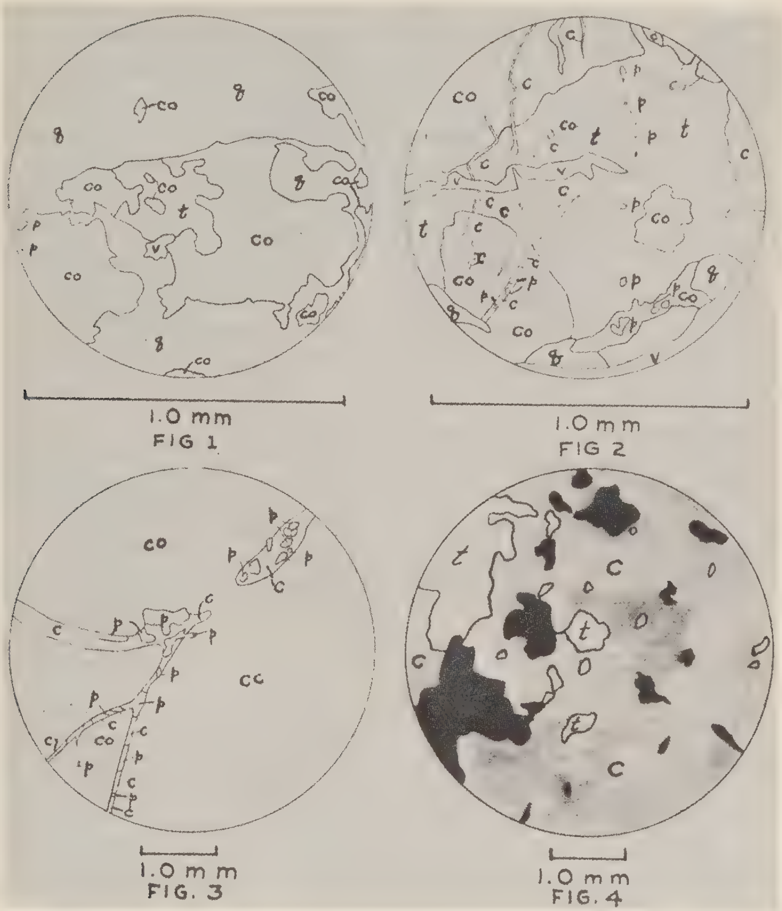

FIG 1 FIG 2 FIG. 3 FIG. 4

Explanation Plate I.

FIG. 1. Camera lucida drawing showing unmixing texture of tetrahedrite and colusite. *t*, tetrahedrite; *co*, colusite; *q*, quartz; *p*, pyrite, and *v*, void.

FIG. 2. Camera lucida drawing showing relations of tetrahedrite, *t;* colusite, *co;* quartz, *q;* chalcocite (with some bornite), *c;* and pyrite, *p;* *v*, void.

FIG. 3. Camera lucida drawing showing detail relations of chalcocite and pyrite in veinlets traversing colusite. *co*, colusite; *p*, pyrite; and *c*, chalcocite. The chalcocite in these veinlets contains little or no bornite.

FIG. 4. Line drawing made by tracing a photomicrograph showing unmixing texture of tetrahedrite and colusite.

t, tetrahedrite; *c*, colusite. The black areas are quartz. The small light colored areas within the colusite are tetrahedrite.

hedrite. Chalcocite without bornite occurs in the smaller of these veinlets. Within the veinlets are small blebs of pyrite oriented in lines, suggesting that pyrite first filled the fractures and later bornite and chalcocite replaced the pyrite. See Figs. 2 and 3. Since the boundaries between colusite or tetrahedrite and bornite or chalcocite are sharp, and since these minerals occupy fractures once filled by pyrite, it seems certain that the pyrite did not replace colusite or tetrahedrite but merely filled the fractures.

Quartz is chiefly earlier than the sulphides, but also occurs in small veinlets cutting the sulphides, indicating that it formed in two generations, one very early, and one rather late. The early quartz in many places shows its crystal outlines against the sulphides. The later quartz occurring in veinlets tends to form irregular grains without definite crystal faces, although in some of the veinlets crystal faces of quartz are present.

The relations just described are represented graphically below:

early
quartz
————early
pyrite
————
colusite &
————
tetrahedrite Time of fracturing
——
late
pyrite
————
chalcocite &
————
bornite
late
quartz
————

The history of mineralization may be summarized as follows: (1) Early solutions precipitated quartz and pyrite. (2) Colusite and tetrahedrite followed, and in part, accompanied pyrite. These minerals may have replaced pyrite to some extent, but whether they did or did not is uncertain. (3) Following a period of fracturing more pyrite was introduced. This pyrite seems to have merely filled fractures in the earlier minerals. (4) Chalcocite and bornite, the last metallic minerals, replaced pyrite, but did not affect either colusite or tetrahedrite. Evidently the precipitation of pyrite had ceased before the chalcocite-bornite solutions arrived since no chalcopyrite is observed. Had copper been present while iron and sulphur were forming pyrite it no doubt would have entered into the reaction in the form of chalcopyrite. (5) The deposition of small amounts of quartz closed the sequence of mineralization.

Summary

Colusite is a new mineral species belonging to the sphalerite group. Chemically it is a sulphide of copper, iron, tin, molybdenum, and zinc which are isomorphous. Arsenic, tellurium and antimony are isomorphous with sulphur. Colusite is bronzy in color, has a hardness of 3 to 4, and a specific gravity of 4.2. It occurs as a primary mineral in various copper veins at Butte, Montana, together with chalcocite, pyrite, and other sulphides. Its relations to other primary minerals are described.

X-RAY EXAMINATION OF COLUSITE, $(Cu, Fe, Mo, Sn)_4(S, As, Te)_{3-4}$

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Ryerson Physical Laboratory, University of Chicago.

Through the courtesv of Professor R. E. Landon I was given the opportunity to make an *x*-ray examination of the newly discovered mineral colusite.

From the material placed at my disposal I was able to select a fragment of a crystal showing two faces. With this crystal fragment a series of oscillation photographs were taken. In addition I examined the crystal by means of the powder method. The oscillation as well as the powder photographs were taken with $MoK\alpha$ radiation. For the powder photographs a camera of radius 20.32 cm. was used. The powder of colusite was mixed with rock salt and the sample placed in a thin glass capillary. In this manner the $\alpha_1\alpha_2$ doublet was resolved over almost the entire range of angles and the displacement of the colusite diffraction lines with respect to the closest rock salt lines were measured. All measurements were made on the α_1 lines. In the oscillation photographs the crystal was rocked through an angle of 15°. The distance from the crystal to the photographic plate was 5.00 cm.

The observations show that the crystal is cubic. No deviation from holohedral symmetry could be detected in the oscillation photographs. The translation lattice is face centered. Long exposure photographs (both oscillation and powder photographs) were taken in order to determine whether very weak reflections might be obtained indicating either a larger unit cell or another type of translation lattice. No positive evidence of the presence of additional lines could, however, be found.

The edge of the unit cell was found to be:

$$a = 5.304 \pm .001\,\text{Å}$$

This value was found on the basis of 5.628Å for the edge of the unit cube of rock salt and a wave length of .7078Å for the $MoK\alpha_1$ line.

For the density Professor Landon gave the value $4.2 \pm .1$. Hence the average molecular weight of the atoms associated with each unit cell is 380 ± 9.

On the basis of the chemical analysis given by Professor Landon we are now in position to calculate the average number of atoms per unit cell. We find:

Sn	0.22 atoms per unit cell		
Mo	0.35 “ “ “ “	Sb	0.02 atoms per unit cell
Zn	0.05 “ “ “ “	Te	0.09 “ “ “ “
Cu	2.13 “ “ “ “	As	0.12 “ “ “ “
Fe	1.24 “ “ “ “	S	2.85 “ “ “ “
	3.99		3.08

In the above list atoms which are capable of replacing each other isomorphously have been grouped together.

The fact that the translation lattice has been found to be face centered requires that the number of equivalent atoms per unit cell be divisible by 4. This requirement is fulfilled as far as the metal atoms are concerned, but not by the sulphur atoms. As the possibility of a larger unit cell or of a different type of translation lattice has been fairly definitely ruled out, it becomes necessary to assume that the sulphur atoms are arranged in fourfold positions. Since there are only 3.08 atoms per unit cell and four available positions, it means that there is about one vacant position per unit cell. These vacant positions must be distributed in a random way throughout the lattice.

According to the above discussion it appears that the logical way of writing the chemical formula would be:

$$(\mathrm{Cu, Fe, Mo, Sn, Zn})_4(\mathrm{S, As, Te, Sb})_{3-4}.$$

Because of the face centered translation lattice the atomic arrangement must be derived either from the normal rock salt type of structure or from the normal sphalerite structure. On the basis of the observed intensities the first possibility can be ruled out quite definitely. The sphalerite type of structure, however, accounts satisfactorily for the observed intensities. The structure amplitudes of Table 2 and the intensities of Table 1 have been calculated on the following basis: For the metal atoms I have used the scattering power for Cu calculated by means of Thomas' method.[1] The F-curve for sulphur is given by James and Brindley[2] and by Pauling and Sherman.[3] These values have been reduced by 25 percent in order to take into account the fact that about 25 percent of the sulphur positions in the sphalerite lattice are vacant in colusite.

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[1] L. H. Thomas, *Proc. Cambridge Phil. Soc.*, **23,** 5, 542, 1927.

[2] James and Brindley, *Zeit. f. Krist.*, **78,** 470, 1931.

[3] Pauling and Sherman, *Zeit. f. Krist.*, **81,** 1, 1932.

Table 1. Observations from a Powder Photograph[a]

$\sin^2\theta = (h^2+k^2+l^2)\times\lambda^2/4a^2$	*hkl*	*Int. obs.*	*Int. calc.*
.01346= 3×.004487	111	vs	31.2
.01778 4×.004445	200	m	5.2
.03569 8×.004461	220	vs	19.1
.04901 11×.004455	311	s+	14.1
.05359 12×.004466	222	w−	1.3
.07138 16×.004461	400	m	3.3
.08441 19×.004443	331	s−	5.8
.08923 20×.004462	420	w−	1.8
.10685 24×.004452	422	s	6.5
.11991 27×.004441	511, 333	m	4.2
.14215 32×.004442	440	w	1.9
.15582 35×.004452	531	m	3.9
.16028 36×.004452	442, 600	vw−	0.7
.17807 40×.004452	620	w+	2.5
.19121 43×.004447	533	vw	1.3
.19590 44×.004452	622	vvw	0.4
.21343 48×.004446	444	vw	0.6
.22695 51×.004450	711, 551	w−	1.8
	640	nil	0.3
.24954 56×.004456	642	w+	2.4
.26304 59×.004458	731, 553	vw	2.0

$$\lambda^2/4a^2 = .004451_8 \pm .000001_5$$
$$a = 5.304_2 \pm .000_9 \text{ A}$$

[a] Concerning calculation of limits of error see: E. Broch, *Zeit. f. phys. Chem.*, **127,** 446, 1927.

Table 2. Observations from Oscillation Photographs

hkl	*Int. obs.*	*F calc.*
111	s	24.4
200	m	13.3
220	s+	25.9
311	s	18.6
400	s+	21.9
331	s−	16.1
420	w−	9.1
422	s−	19.4
511	w+	14.4
440	m+	17.7
531	w	13.2

The observed intensities from the oscillation photographs are compared directly with the calculated structure amplitudes in the absence of any knowledge of the amount of secondary extinction. The calculated intensities for the powder photographs have been obtained with the usual relation:

$$\text{Intensity} \propto \frac{(F)^2\, p(1+\cos^2 2\theta)}{\text{Sin}^2\,\theta\cdot\cos\,\theta}$$

The distance from metal atom to that of sulphur was determined to be 2.298Å. This value compares very well with the distance calculated from Goldschmidt's radii for atomic binding.[4] It is to be remarked, however, that the effect of the missing sulphur atoms would be to reduce the interatomic distance.

Cases like the present one in which there are too few atoms to fill all the points in a set of equivalent positions have been established previously for other minerals. The most striking examples from the mineralogical point of view are those of hornblende, $(Ca,Na,K)_{2-3}(Mg,Fe,Al)_5(Si,Al)_8O_{22}(OH)_2$ and pyrrhotite, $Fe_{1-x}S$.

SUMMARY

X-ray examinations show that the new mineral colusite is cubic, with a length of the edge of the unit cube = 5.304 ± .001 Å.

The correct manner of writing the chemical formula is:

$$(Cu, Fe, Mo, Sn, Zn)_4(S, As, Te, Sb)_{3-4}.$$

The atomic arrangement is essentially the same as in sphalerite; however, with about $\frac{1}{4}$ of the sulphur atoms removed at random. Accordingly the mineral should be classified as a new member of the sphalerite group.

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[4] V. M. Goldschmidt, Geochemische Verteilungsgesetze der Elemente, VII, Oslo, 1926.

STRUCTURAL CRYSTALLOGRAPHY[1]

AUSTIN F. ROGERS, *Stanford University.*

For the branch of science concerned with the internal structure of crystals, various names, such as leptology or leptonology (Rinne), roentgenography (V. Goldschmidt), *x*-ray crystallography (the title of a recent book by R. W. James, New York, 1930), crystal stereochemistry (Rinne), new or modern crystallography, and possibly others have been used.

Objections may be raised to all of these. Leptology (from the Greek, *lepton*, fine or delicate) is perhaps the best, if one is to use an entirely new term, but this hardly seems necessary or even desirable. Roentgenography is unsuitable since it is widely used in a different sense, *viz.*, for the art of producing *x*-ray photographs especially for medical and dental work. Of the various terms enumerated, *x*-ray crystallography is perhaps the one most generally used. This term is a good one in that it implies that the science under discussion is a branch of crystallography, but *x*-rays are simply means used in the elucidation of crystal structure. It is also true that the theoretical aspects of this science were well developed before *x*-rays were used or even discovered. The term stereochemistry has long been used in a special sense in organic chemistry. The use of "new or modern crystallography" as contrasted with older or classical crystallography is in my opinion unfortunate as it implies that geometrical crystallography is out of date. As Victor Goldschmidt[2] has expressed it, "The morphologists are old-fashioned folk; their methods are superseded." Without the background of geometrical crystallography a science dealing with the internal structure of crystals could never have been developed. Again it is certainly true that the use of *x*-rays does not furnish complete information about a crystal; there are yet further advances to be made, especially in regard to the surface features of a crystal. Such a term as modern crystallography, therefore, has at best only a temporary value.

For this division of crystallography concerned with the internal structure of crystals, I propose the term *structural crystallography* coördinate with geometrical, physical, and chemical crystallography. We then have the following classification:

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[1] Paper read before the eleventh annual meeting of *The Mineralogical Society of America* at Toronto, December 30, 1930.

[2] *American Mineralogist*, Vol. **16**, p. 32, 1931.

$$\text{Crystallography}\left\{\begin{array}{l}\text{Geometrical}\\ \text{Structural}\\ \text{Physical}\\ \text{Chemical}\end{array}\right.$$

Crystallography is often used in the narrow or restricted sense of geometrical crystallography or crystal morphology, but there are many arguments in favor of the broad use of the term. The internal structure, the transmission of radiant energy through crystals, and the relation between crystal form and chemical composition are so closely related to the external form that they demand treatment in the complete science of crystals which we call crystallography.

A quarter of a century or so ago it was common to find the term crystallography used in the restricted sense, but there is an increasing tendency to employ it with the more comprehensive meaning. In books published within the last decade I find that in only five[3] is crystallography used in the narrow sense of geometrical crystallography. Only one English dictionary, the Standard, gives a broad definition of crystallography, but dictionaries are often out-of-date when it comes to scientific terms.

To some a three-fold division of crystallography with structural crystallography as a subdivision of physical crystallography is preferable. Professor E. H. Kraus[4] so expressed himself. The same view is apparently held by Niggli, for the sub-title on the cover page of the "Zeitschrift für Kristallographie" is "Kristallgeometrie, Kristallphysik, Kristallchemie." While the strictly experimental side of structural crystallography might logically be placed under physical crystallography, the consideration of space-lattices, and space-groups could be included under geometrical crystallography. But these two parts of crystallography should be considered together and not in separate divisions. The objects and methods of structural crystallography are so different from those of other branches of crystallography that it should stand as an independent division of the complete science of crystallography.

[3] Ford, *Manual of Mineralogy*, 14th ed., New York, **1929.**
Dana-Ford, *Text-book of Mineralogy*, 4th ed., N. Y., **1932.**
Evans and Davies, *Elementary Crystallography*, London, **1924.**
Barker, *Systematic Crystallography*, London, **1930.**
Winchell, *Elements of Optical Mineralogy*, 3rd ed., N. Y., **1928.**

[4] Oral communication. December 30, 1930.

The following tabulation presents a brief summary of some of the important events in the development of structural crystallography.

IMPORTANT EVENTS IN THE DEVELOPMENT OF STRUCTURAL CRYSTALLOGRAPHY

1849	Bravais	14 Space-Lattices
1879	Sohncke	65 Point-Systems
1890	Fedorov	230 Space-Groups
1891	Schoenflies	
1894	Barlow	
1904	Groth	"Crystals consist of n interpenetrating point-systems of atoms"
1905	Friedel	Law of Rational Symmetric Intercepts
1912	Laue Friedrich Knipping	Crystal Structure revealed by x-rays
1913	Bragg, W. H.	x-ray Spectrometer
1914	Canac	Determination of Axial Ratio by x-Rays
1915	Nishikawa	Application of Space-Groups
1916	Debye and Scherrer	Powder Method
1917	Hull	
1922	Schiebold	Rotating Crystal Method
1926	Greenwood	x-Ray Goniometer

Contrary to general opinion this science did not spring suddenly into existence with the discovery in 1912 that a crystal may act as a diffraction grating for x-rays. More than half a century before, Bravais made a substantial contribution toward the solution of the problem of crystal structure from the theoretical side. This theoretical work culminated in the discovery of the 230 space-groups at the hands of Fedorov in 1890. In 1904 Groth in an address before the British Association for the Advancement of Science stated that "a crystal consists of n interpenetrating point-systems of atoms," which was verified about a decade later. In 1905 Friedel formulated the law of rational symmetric intercepts,[5] which practically proved the existence of space-lattices in crystals, seven years before direct proof was furnished by the work of Laue and his associates in 1912.

The direct experimental approach to the problems of crystal structure has given a wonderful impetus to the study of structural crystallography and its growth has been much more rapid than that of the other divisions of crystallography. The results of x-ray analysis have for the first time aroused the interest of chemists and physicists generally in crystals. There is some danger that structural crystallography through its great achievements may dominate crystallography just as the latter was once dominated by geometrical crystallography. That in my opinion would be unfortunate. All divisions of crystallography are useful; the neglect of any one of them may be detrimental to the others.

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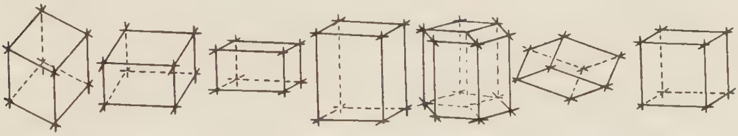
[5] See article by author, *American Mineralogist*, Vol. **10**, p. 181, 1925.

Before concluding I wish to point out that there are seven fundamental or primary space-lattices. This has not been generally recognized. Seven of the 14 Bravais lattices may be derived from the other seven or primary lattices by translations. Thus the body-centered cube is derived from the cube by a translation equal to one-half the cube-diagonal. The 14 Bravais lattices are of course very important in x-ray analysis, but the recognition of the seven fundamental lattices simplifies the study of elementary structural crystallography. Unit cells of the seven fundamental lattices are illustrated by the accompanying figures:



The Seven Primary Space-Lattices. (From left to right these are: triclinic, monoclinic, orthorhombic, tetragonal, hexagonal, rhombohedral and isometric.)

Since all crystals have one of them as an ultimate framework, these seven fundamental lattices suggest a basis for the definition of crystal systems. Satisfactory definitions of the crystal systems are sadly lacking in nearly all text-books and treatises on crystallography. In fact some crystallographers, especially those of the French school, make the character of the space-lattice the basis for the crystal system; in this they follow the example of Bravais. This gives seven crystal systems, the holosymmetric class of each system having the symmetry of one of the primary space-lattices.

Let us note the relation between the crystal systems and the primary space-lattices which is expressed in the following tabulation. In the triclinic, monoclinic, orthorhombic, tetragonal, and isometric systems there is a clear-cut correspondence, but when we

PRIMARY SPACE LATTICES FOR THE VARIOUS CRYSTAL SYSTEMS

Triclinic System	Oblique Rhomboidal Prism	Γ_{tr}
Monoclinic System	Oblique Rectangular Prism	Γ_m
Orthorhombic System	Right Rectangular Prism	Γ_o
Tetragonal System	Right Square Prism	Γ_t
Hexagonal System		
Rhombohedral Subsystem	Rhombohedron	Γ_{rh}
	Hexagonal Prism with centered base	Γ_h
Hexagonal Subsystem	Hexagonal Prism with centered base	Γ_h
Isometric System	Cube	Γ_c

come to the twelve classes with a single axis of 3-fold or 6-fold symmetry there are difficulties. These twelve classes are either placed in one system, the hexagonal, or in two systems, the hexagonal and the rhombohedral. The difficulty in using two systems and making the lattice the basis of the system is that each of the five classes [A_3, $\text{Æ}_6(C)$, $A_3 \cdot 3A_2$, $A_3 \cdot 3P$, $\text{Æ}_6 \cdot 3A_2 \cdot 3P(C)$][6] placed in the rhombohedral system may have either the hexagonal prism or the rhombohedron as the fundamental lattice. This means that the crystals of these five classes may belong to either the hexagonal or the rhombohedral system. Now this gives to the crystal system a meaning different from the original meaning of the term. The term crystal system is now so firmly established in the original sense that it is too late to make a change, even if that change were desirable, which is very doubtful. It is clear, then, that crystal systems cannot be based upon space-lattices.

The most satisfactory disposition of the twelve classes mentioned is to place them in one system, the hexagonal, with two subsystems: the hexagonal subsystem of seven classes each with the hexagonal prismatic lattice and the rhombohedral subsystem of five classes each with both the hexagonal prismatic and the rhombohedral lattices.

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[6] The character Æ_6 is used as a symbol for a composite six-fold axis of rotatory-reflection.

ARTIFICIAL JAROSITES—THE SEPARATION OF POTASSIUM FROM CESIUM[1]

J. G. Fairchild, *U. S. Geological Survey.*

Abstract

Mitscherlich[2] prepared alunite and jarosite, $K_2O \cdot 3Fe_2O_3 \cdot 4SO_3 \cdot 6H_2O$, at 230°C. by heating the sulphates in a closed tube but the writer has obtained good crystals of jarosite at temperatures as low as 110°C. and nearly equal in size to those of the natural mineral. Higher temperatures may be used, in order to increase the yield by promoting more rapid hydrolysis of the iron salt, but a temperature as low as 90°C. produces a basic sulphate of iron and potassium containing twice as much water and less alkali metal. At temperatures above 110°C. cesium, if present, does not enter the jarosite molecule.

Introduction

About five different jarosites occur in nature. These are the potassium or ordinary jarosite, natrojarosite, ammoniojarosite, argentojarosite, and plumbojarosite. Of these, the potassium compound became of interest to the writer because of the lack of information in the literature regarding its preparation under laboratory conditions, the experiments of Mitscherlich apparently being the only ones on record.

Several attempts by the writer to prepare jarosite, $K_2O \cdot 3Fe_2O_3 \cdot 4SO_3 \cdot 6H_2O$, at a steam bath temperature have yielded basic sulphates of varying compositions but possessing simple molecular ratios. Two or three different compounds obtained at this temperature, but made from different porportions of the reagents, potassium and ferric sulphates, were analyzed. They were not altogether insoluble in water, thereby differing from jarosite. Optically, they were biaxial and varied in sign. The lowest index was slightly less than 1.70, the highest about 1.80. The crystals were minute and of a lighter brown color than jarosite, which is uniaxial (−) with $\epsilon = 1.71$, $\omega = 1.80$, for both the artificial and the natural mineral. Dana gives $\omega = 1.820$, and Larsen $1.82 \pm .01$.

Conditions Favoring the Formation of Jarosite

From its formula, jarosite should require 1 mole K_2SO_4:3 moles $Fe_2(SO_4)_3$, or 0.17 gram to 1.2 gram. To provide for about 20 percent excess of ferric sulphate 0.19 and 1.6 grams, respectively, were dissolved in 20 cc. of 0.75 *N* H_2SO_4 and the solution was heated in a sealed pyrex tube for 24 hours at 110° C. The test was continued 24 hours longer at 165°–180°. The purpose of the acid is to favor larger crystals by retarding the hydrolysis of the ferric sulphate. After washing the crystals in water they were examined optically and found to have the color and habit of jarosite—small rhombohedrons. The indices were found as given above. The analysis is shown in Table 1.

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[1] Published by permission of the Director of the U. S. Geological Survey.

[2] Hintze, Handbuch der Mineralogie, vol. **1**, pt. 3:2, p. 4182.

Table 1. Analysis of Artificial Potassium Jarosite

	Percent	Ratios
Fe_2O_3	48.1	301 or 3.0
SO_3	32.1	401 or 4.0
K_2O	9.5	101 or 1.0
H_2O (diff.)	10.3	572 or 5.7
	100.0	

Other Jarosites

A solution of ferric sulphate containing lithium sulphate was similarly treated, but no crystals developed. After potassium sulphate was added to this solution the jarosite produced was tested for lithium; none was found. No definite jarosite crystals were formed containing copper, gold, or cesium. The absence of cesium was determined by use of the spectroscope. Gold, which was present as aurous chloride, seemed to be reduced to the finely divided metal.

Rubidium jarosite was prepared under conditions similar to those already given using an acidity 1.5 *N* in H_2SO_4. The reagent used contained only 85 percent of the pure rubidium salt, 15 percent being potassium. The analysis of the product is shown in Table 2.

Table 2. Analysis of Rubidium Jarosite

	Percent	Ratios	
Fe_2O_3	45.8	286 or 2.9	
SO_3	31.3	390 or 3.9	
Rb_2O	9.5	51	0.8
K_2O	2.8	30	
H_2O	11.2	622	6.2
	100.6		

A second jarosite prepared from a rubidium salt nearly free from potassium gave a smaller yield of crystals which contained sodium, evidently introduced from the glass tube. The usual quantity of these crystals was about 1 gram. It thus appears somewhat doubtful whether a rubidium jarosite could be prepared free from sodium or potassium. Such a test could not be conducted in glass. The mother liquors from the three tests with rubidium were combined and analyzed in order to show the extent to which the small quantity of potassium entered the jarosite molecule. The percentage of platinum in the mixed chloroplatinates gave the rubidium.

TABLE 3. SEPARATION OF K_2SO_4 FROM Rb_2SO_4

Alkalies taken (g.)		Alkalies left in mother liquor (g.)	
K_2SO_4	0.154	K_2SO_4	None ?
Rb_2SO_4	1.130	Rb_2SO_4	0.488

The order of preference among the alkalies appears to be potassium, rubidium, and sodium. Natrojarosite could no doubt be prepared in similar manner, also an ammonium jarosite.

The optical properties of the analyzed rubidium jarosite are: Uniaxial (−); $\epsilon=1.720$, $\omega=1.805$; cleavage $\{0001\}$ dist.; color brown. These properties are about the same as for ordinary jarosite.

Argentojarosite and plumbojarosite were also prepared. Although the products were too small, for a complete analysis, Ag_2O was determined as 19.1 percent, compared with 20.3 percent for the theoretical amount. A qualitative test for lead confirmed plumbojarosite. Argentojarosite was prepared from a saturated solution of silver sulphate, 1.5 N to 3 N in H_2SO_4 in order to prevent the formation of an hydroxyjarosite. Plumbojarosite was prepared from a solution containing 0.3 g. lead chloride in 1.5 N HCl, this acid being required to retard the precipitation of lead sulphate. These two tests were continued for three days, the lead compound being particularly slow to crystallize.

The optical properties, as determined by Miss J. J. Glass, of the U. S. Geological Survey, are: Argentojarosite, uniaxial (−), $\epsilon=1.785$, $\omega=1.880$; plumbojarosite, uniaxial (−), $\epsilon=1.783$, $\omega=1.870$; pleochroism: $\epsilon=$yellow, $\omega=$brown for both minerals. These indices were found to agree with determinations on the natural minerals, although Dana gives $\omega=1.905$ for argentojarosite.

THE SEPARATION OF POTASSIUM FROM CESIUM

When the hydrolysis of potassium and ferric sulphates proceeds at steam bath temperature, a fine-grained basic sulphate is deposited. Although its composition may vary slightly according to the quantity of sulphuric acid liberated, yet the following analysis may be given as representative of a typical product, which is also water insoluble like jarosite.

TABLE 4. ANALYSIS OF SUBSTANCE PREPARED AT STEAM BATH TEMPERATURE

	Percent	Ratios	
Fe_2O_3	44.60	279 or	4.0
SO_3	33.50	419	6.0
K_2O	7.24	77	1.1
H_2O	15.07	837	12.0
	100.41		

As much as 5 grams of potassium sulphate may be removed from a solution containing 2 mg. of cesium sulphate without complete absorption of the cesium by the precipitate as shown by the following procedure: Prepare a solution containing 40 grams of anhydrous ferric sulphate in 600 cc. of 0.2 N H_2SO_4 to which has been added the previously dissolved potassium sulphate. The whole is placed in a round bottom flask and immersed in a steam bath. A small funnel may be inserted in the neck of the flask in order to retard evaporation. Briefly stated, the process involves three 24-hour periods of hydrolysis with two intervening neutralizations of the greater part of the liberated acid with a little sodium hydroxide dissolved in water, until about 1 gram of iron sulphate remains in solution. After each period of hydrolysis the remaining sulphate solution is put in a clean flask and the heating is continued at one half the previous volume. The final volume after hydrolysis is 150 cc. Concentration is further continued to 50 cc. when any cesium is twice precipitated with the residual potassium as chloroplatinate to free it from sodium and iron. Cesium was confirmed spectroscopically.

TABLE 5. SEPARATION OF POTASSIUM AND RECOVERY OF CESIUM

Alkalies taken (g.)		Alkalies recovered in the solution (g.)	
K_2SO_4	Cs_2SO_4	K_2SO_4	Cs_2SO_4
2.	.020	None?	.020
2.	.002	.013	.0006
5.	.002	.068	Trace

For concentrating very small percentages of cesium this method is not very satisfactory, as small percentages seem to be carried down with the insoluble iron compound, together with the potassium. Thus only a separation from sodium could be obtained. Sodium, for the most part, remains with the cesium in the presence of potassium. The ferric sulphate should preferably be limited to about 7 times the weight of the potassium sulphate, as a slight loss of cesium occurs with even this proportion. This loss is not easily explained.

Behavior of Rubidium

At steam bath temperature rubidium is not removed from solution as it is at higher temperatures in the jarosite molecule, as described above, although small quantities—10 mg. or less of rubidium sulphate in 2.0 g. of potassium sulphate,—are apparently removed from the solution in a similar manner to cesium.

Summary

Four artificial jarosites, the potassium, the rubidium, the lead and the silver, have been prepared, by heating solutions of the respective sulphates to temperatures from 110° to 200° C. By a similar procedure at steam bath temperature it is possible to separate relatively large proportions of potassium from moderate proportions of cesium and rubidium.

NOTES AND NEWS

CORONADITE "REDIVIVUS"

Waldemar Lindgren, *Mass. Inst. of Technology.*

In 1905, W. F. Hillebrand and myself published some notes on a new mineral from the Coronado vein, Morenci, Arizona,[1] to which the tentative formula of $3MnO_2 \cdot PbO$ was given. The mineral was examined carefully, and there was no doubt in our minds that it was substantially homogeneous and represented a new species.

In 1923, a short note on this mineral was published by E. E. Fairbanks,[2] in which it was maintained that the so-called coronadite consisted mainly of a galena-white mineral with a brown streak, through which is a finely disseminated substance which shows polarization with crossed nicols. The galena-white mineral was called hollandite (psilomelane), and the disseminated substance was referred to as an unidentified lead mineral. Thus died coronadite, and on its tombstone Dana-Ford, 4th edition, p. 495, wrote that coronadite was shown to be a mixture.

Morenci, Arizona

Recalculated to 100 percent. Traces of vanadium.

(W. F. Hillebrand, Analyst)

MnO_2	60.80
MnO	7.12
PbO	28.66
ZnO	0.11
CuO	0.05
Al_2O_3	0.68
Fe_2O_3	1.10
MoO_3	0.37
H_2O	1.11
	100.00

Bou Tazoult, Morocco

(G. Campredon, Analyst)

MnO_2	59.60
MnO	8.02
PbO	28.68
BaO	0.23
CaO	0.05
CuO	0.14
Al_2O_3	0.10
Fe_2O_3	0.60
P_2O_5	0.03
As_2O_5	0.04
V_2O_5	0.20
SO_3	0.02
CO_2	0.04
H_2O+	1.80
SiO_2	0.26
	99.81

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[1] W. Lindgren, The copper deposits of Clifton-Morenci: *Prof. Paper* **43,** *U. S. Geol. Survey,* 1905, pp. 103–106.

[2] E. E. Fairbanks, Mineragraphic notes on manganese minerals: *Am. Mineralogist,* **8,** 1923, pp. 209–210.

Now we come to the resurrection. In 1932, J. Orcel[3] published a description in the *Comptes Rendus* of a mineral from Morocco, which proved to have a composition identical with the old coronadite of Lindgren and Hillebrand. The two analyses are given above.

There can be no reasonable doubt as to the identity of the two substances, and Orcel gives the following formula as the most probable: $2MnO_2 \cdot PbO$. The occurrence in Morocco is in the upper levels of an important manganese deposit.

Much encouraged, naturally, by this new development, particularly as Mr. Orcel had the kindness to send me a beautifully polished specimen of the coronadite from Morocco, I set about to ascertain something more about the original occurrence. Apparently the specimen which Mr. Fairbanks had examined came from the Harvard Mineralogical Museum; it was collected by W. F. Ferrier, and now forms a part of the Holden Collection. I was allowed to examine it through the kindness of Professor Charles Palache.

It consists essentially of quartz grains with some decomposed silicates between which veinlets and masses of the questionable minerals are embedded; it is not nearly as good as the original specimen analyzed by Hillebrand. The mineral appears as a dark gray to black material, and in places has an extremely finely fibrous structure whereas other parts are fine granular. Any of this dark material gives a strong reaction for lead by the iodide method.

In Professional Paper 43, the hardness was given as 4, which is not quite correct; it is more nearly 5. The specific gravity of the analyzed material was 5.246, but the material contained 7 percent SiO_2 and the figure is, therefore, too low. Orcel obtained 5.505. The highest specific gravity of the other manganese oxide minerals is 4.9 ranging from this to 3.3. The higher specific gravity of the coronadite is naturally caused by the lead.

Polished sections show veins of an almost galena-white mineral with granular to fine fibrous texture. The reflectivity is high, probably corresponding closely to Orcel's figures (0.31 to 0.34). It is strongly anisotropic with dark brown to gray colors. In places it is decomposing to a cryptocrystalline black metallic mineral, which also spreads in small veinlets; it is probably some variety of psilomelane. The texture and polarization of the coronadite corresponds exactly to Orcel's description. The data given by Fairbanks are incomplete and obscure. Evidently he thought that the "galena-white" mineral was hollandite. He makes no statement as to its anisotropism. What he means by the "finely disseminated substance which shows polarization by crossed nicols" is not clear to me. I think we may safely discard his diagnosis and admit the identity of the coronadite from Morenci with Orcel's coronadite from Bou Tazoult.

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[3] J. Orcel, Sur l'existence de la coronadite dans les minérais de manganèse de Bou Tazoult, région de l'Imini (Maroc): *Comptes Rendus, Acad. Sci.*, séance du 30 Mai, 1932.

J. Orcel et St. Pavlovitch, Charactères microscopiques en lumière réfléchie de quelques minerais oxydés de manganèse: *Bull. Soc. française de Mineralogie*, **54,** p. 145, 1931.

Orcel's formula $2MnO_2 \cdot PbO$ is probably correct; the small amount of water appears to represent the beginning of a leaching of lead and a change towards psilomelane.

Thus, the mineral is rescued and resuscitated.

ERRATA

In the article by J. D. H. Donnay and J. Mélon, June issue 1933, kindly note the following corrections:

Page 231. The last eight lines of Table 2 should be placed on top of p. 232, so as to have the forms listed according to increasing values of S^2.

Page 234. Table 4, column III: face No. **6** should be $20\bar{1}$ instead of 201.

Page 240. Table 5: The sixth and seventh lines of forms should read:

$10\bar{1}$ $0\bar{1}1$ $1\bar{1}0$ 110 011 101

and

$\bar{1}\bar{1}1$ $\bar{1}11$ $1\bar{1}1$ 111

instead of

$10\bar{1}$ $1\bar{1}0$ $1\bar{1}0$ 110 011 101

and

$\bar{1}\bar{1}1$ $\bar{1}11$ $11\bar{1}$ 111

THE MINERALOGICAL SOCIETY OF AMERICA

Fourteenth Annual Meeting

HERBERT P. WHITLOCK, *President*

Chicago, Illinois

December 28–30, 1933

PROGRAM

In joint session with the Geological Society of America. Friday, December 29, 1933, at 12 o'clock, noon.

HERBERT P. WHITLOCK, *Presidental Address:* **A Century of Progress in Crystallography.**

LIST OF PAPERS

To be presented Thursday, December 28, 1933, after the business session at 2 P.M., and thereafter at the regular sessions on Friday and Saturday if not previously completed.

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CHARLES PALACHE—**Contributions to crystallography:** a) *claudeite;* b) *minasragrite;* c) *samsonite;* d) *native selenium;* e) *indium.*

CHARLES PALACHE—**Crystallography of the Uranium Oxides.**

CHARLES PALACHE—**Pseudobrookite.**

A. L. PARSONS—**An Unusual Calcite Crystal from Godfrey, Ontario.**

A. L. PARSONS—**A Simple and Inexpensive Sheet for Gnomonic and Stereographic Projections.**

AUSTIN F. ROGERS—**Zones as a Basis for the Definition of Crystal Systems.**

R. C. EMMONS AND E. F. WILLIAMS—**A High Index Refractometer.**

THEODORE A. DODGE—**Determination of Optic Angle with the Universal Stage.**

J. D. H. DONNAY, G. TUNELL, AND T. F. W. BARTH—**The Various Modes of Attack in Crystallographic Investigation.**

R. C. EMMONS—**Plagioclase Determination by the Modified Universal Stage.**

JOHN W. GRUNER—**Relation of Silicate Sheet Structures—Demonstration with Models.**

G. TUNELL AND C. J. KSANDA—**The Relation of X-ray Goniometer Data to Reflection Goniometer Measurements on Sylvanite.**

C. S. Hurlburt, Jr., and A. F. Gonyer—**A New Group of Phosphates.**

W. A. Tarr—**A Study of the Linnaeite Group of Sulphides.**

Charles Palache—**Minerals from Topaz Mountain, Utah.**

C. B. Slawson—**Sussexite from Iron County, Michigan.**

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Carl R. Schwartzlow—**Two Dimensional Dendrites and their Origin.**

Lloyd F. Fisher—**Growth of Stalactites.**

J. F. Schairer and N. L. Bowen—**Preliminary report on the System,** $K_2O \cdot Al_2O_3 \cdot SiO_2$.

A. P. Beaven and J. E. Hawley—**Mineralogy and Genesis of the Mayville Iron Ore of Wisconsin.**

H. N. Fisk—**The Significance of Three Generations of Plagioclase in an Andesite-basalt Flow.**

Duncan Stewart, Jr.—**The Petrography of the Beacon Sandstone of South Victoria Land.**

Lincoln Dryden—**Statistical Correlation of Heavy Mineral Suites.**

A. E. Alexander—**Some Interesting Heavy Minerals from the Sediments Collected on the Continental Shelf off Northeastern United States.**

J. J. Runner—**The Association of Certain Igneous and Sedimentary Amphibolites.**

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Edward H. Watson—**Differentiation in Teschenite Sills at El Mulato, Tamaulipas, Mexico.**

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